(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 321 112 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication of patent specification: **17.03.93** (51) Int. Cl.5: **G01B 7/10**

(21) Application number: **88311204.7**

(22) Date of filing: **25.11.88**

(54) **Method for detecting corrosion on conductive containers.**

(30) Priority: **17.12.87 US 134368**

(43) Date of publication of application:
21.06.89 Bulletin 89/25

(45) Publication of the grant of the patent:
17.03.93 Bulletin 93/11

(84) Designated Contracting States:
BE DE FR GB NL SE

(56) References cited:
US-A- 3 315 154

MESSTECHNIK, vol. 79, no. 12, December 1971, pages 284-289, Bohdan Carniol CSc, Prag, CS; A.S. POPOV: "Die Messgrössen-Trennung bei der induktiven Dickenmessung mit Dämpfungsauswertung von Eigenschwingungen"

IECON '84, Int. Conf. on Ind. Electronics, Control and Instrumentation, vol. 2, Tokyo, October 22-26, 1984, pages 759-763, IEEE, New York, US; MAKOTO NEMOTO et al.: "Automatic floor plate thickness measuring equipment"

AUTOMATISME, vol. XV, no. 3, March 1970, pages 114-121; W.K. ROOTS: "Capteurs de dimensions linéaires"

(73) Proprietor: **ATLANTIC RICHFIELD COMPANY**
515 South Flower Street
Los Angeles California 90071(US)

(72) Inventor: **Spies, Brian R.**
Route 7 Box 242A
McKinney Texas 75069(US)

(74) Representative: **Coleman, Stanley et al**
MATHYS & SQUIRE 10 Fleet Street
London EC4Y 1AY (GB)

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid (Art. 99(1) European patent convention).

Rank Xerox (UK) Business Services
(3.10/3.5x/3.0.1)

Description

Field of the Invention

The present invention relates to a non-destructive method for measuring wall thickness and thereby detecting corrosion on electrically conductive containers such as pipelines, storage vessels, pressure vessels and the like.

Background of the Invention

Oil and gas pipelines located at Alaska's Prudhoe Bay are wrapped with a jacket of insulating material to prevent the rapid cooling, and provide better transportability, of oil and gas fluids. The outer surface of the insulation is covered by a metal jacket for keeping out moisture. The metal jacket is typically provided in two half portions with each portion having flanges for aiding in the retention of the jacket on the pipeline. The two half portions of the jacket are joined together at the flanges which form seams. Water occasionally enters through the jacket seams and travels through the insulation to the pipe where it causes corrosion.

Prior art methods of detecting pipeline corrosion have proven inadequate. For example, pigs with corrosion detection equipment can only be used on pipelines that have access locations; many pipelines lack such locations. Ultrasonic detection methods require removal of the metal jacket and insulation, a timely and expensive procedure. Radiography detection methods are potentially hazardous and the equipment is cumbersome, requiring impractical or inconvenient adjacent vehicular support. Furthermore, with radiography methods it is often difficult to distinguish between corrosion pits filled with corrosion products and uncorroded portions of pipe walls. What is needed then is a method of detecting corrosion through insulation and the surrounding jacket, and which method can be practiced with portable equipment.

Electromagnetic probing techniques provide such a method for detecting corrosion through insulation. In the prior art, frequency domain electromagnetic probing techniques are used to detect corrosion in aircraft fuel tanks. Frequency domain electromagnetic probing techniques utilize a small number of frequencies and measure magnitude and phase differentials between the transmitted signals and the received signals. However, because frequency domain techniques, as a practical matter, utilize only a small number of frequencies, the amount of information obtained is inherently limited, thus detracting from the accuracy of the techniques.

An article by Bohdan Carniol in Messtechnik, Vol. 79, No. 12, December 1971, pages 284-289 discloses a method of determining the thickness of an object using electromagnetic techniques. An LC measuring circuit is excited with free oscillations which are damped by an object placed close to the circuit. Only discrete frequencies are employed. From the damping of the oscillations, the thickness of the object can be computed.

In Proceedings IECON '84, International Conference on Industrial Electronics, Control and Instrumentation, Vol 2, Tokyo, October 22-26, 1984, pages 759-763, IEEE, New York, USA, an article by Nemato et al discloses automatic floor plate measuring equipment. In this equipment, eddy currents are induced into an object to which a static magnetic field is applied. This produces an ultrasonic signal which is propogated to a separate receiving area of the object. The time between transmission and receipt of the signal is determined, and from a knowledge of the ultrasonic wave velocity, the thickness of the object is derived.

An article by W.K. Roots in Automatisme, Vol XV, No. 3, March 1970, pages 114-121 discloses an apparatus wherein a coil wound on an insulating support is energised by an alternating current. Eddy currents are induced in a metallic specimen adjacent the coil and these currents generate a magnetic field opposing the field produced by the coil. This results in a reduction in the coil inductance. From this, the thickness of the specimen can be found.

It is an object of the present invention to provide a method for measuring relative wall thickness, and thereby detecting corrosion on insulated conductive containers, wherein said method has improved accuracy in detection and can detect corrosion through insulation.

According to the present invention there is provided a method of measuring wall thickness of container means (for example to detect irregularities such as corrosion) said wall being electrically conductive and having a near surface and a far surface, comprising the steps of placing transmitting antenna means and receiving antenna means in proximity with the near surface of that portion of the container means wall which is to be investigated for corrosion; inducing a transient eddy current into the container means wall portion with the transmitting antenna means; and characterised by

a. receiving a signal indicative of said induced current in said container means wall portion with the receiving antenna means; and

b. comparing the decay of the received signal with a reference decay indicative of a known wall thickness, whereby the thickness of the the container means wall portion can be inferred.

Brief Description of the Drawings

Figure 1 is a schematic diagram showing a typical situation in which the method for detecting corrosion in a container in accordance with a preferred embodiment of the present invention can be practiced, together with typical testing apparatus.

Figure 2 is a schematic diagram showing a transverse cross-section of the pipeline of Figure 1.

Figure 3 is a schematic cross-sectional view showing the antenna means of Figure 2 in detail.

Figure 4 is a graph showing the time domain response curves of various conductors, obtained by the transient electromagnetic probing (TEMP) method of the present invention.

Figure 5 is a graph of the response curve of a pit in a pipe wall, with the response curve obtained by computing the ratio of the "corrosion" to the "no corrosion" response curves of Figure 4.

Fig. 6 is a graph showing a longitudinal cross-sectional TEMP profile of the pit of Fig. 5, with the profile being obtained by averaging the late time responses at each antenna means location.

Fig. 7 is a graph showing the effects of the jacket flanges and of variations in antenna means height on time domain responses of pipe walls.

Fig. 8a is a circumferential map of a portion of a pipe showing both the location of corrosion and ultrasonic wall thickness measurements.

Fig. 8b is a graph showing transverse TEMP profiles of the unjacketed pipe of Fig. 8a, taken along line A-A.

Fig. 8c is a graph showing transverse TEMP profiles of the jacketed pipe of Fig. 8a, taken along line A-A, with the TEMP profiles corrected for the effects of the jacket flanges.

Fig. 8d is a graph showing the same TEMP profiles as in Fig. 8c, but uncorrected for the effects of the jacket flanges.

Description of Preferred Embodiment

In Figs. 1-3 there is schematically shown a typical situation in which the method of detecting corrosion in electrically conductive containers 11 can be practiced, together with typical detecting apparatus 25. The method of the present invention utilizes transient electromagnetic probing (TEMP) to detect corrosion.

The conductive container shown in Figs. 1-3 is a portion of a pipeline 11, which is of course made up of a plurality of individual pipes 13. The pipes 13 have a diameter and the pipe walls 15 have a thickness. The pipe walls 15 are made up of an electrically conductive material such as steel.

In Alaska's Prudhoe Bay region, pipelines wrapped with insulating material 17 are used to transport oil and gas fluids. The insulation 17 is provided to prevent rapid cooling of the oil and gas fluids in the pipeline and thus provide better transportability of these fluids in the pipeline. In refineries, pipelines and vessels are commonly wrapped with insulation as a safety measure in protecting personnel from high temperatures. The insulation 17 on pipelines is typically a thermoplastic foam such a polystyrene, and has a radial thickness. Surrounding the insulation 17 is a metal jacket 19 which is provided to keep out moisture. The jacket 19 has a thickness which is much less than the thickness of the pipe wall. The metal jacket 19 has two half portions that extend longitudinally along the pipeline. Each jacket half portion has seam means in the form of flanges 21 that extend radially outward. When the jacket half portions are assembled onto the pipeline, the respective flanges 21 abut one another to form seams. The half portions are retained in place on a pipeline by securing the respective flanges together with suitable means.

In Fig. 3, the pipe wall 15 is shown to have corrosion pit 23 adjacent to the insulation. The corrosion acts to reduce the thickness of the pipe wall, wherein it forms the pit and fills the pit with corrosion products. The corrosion that has pitted the pipe wall is caused by water that has entered the insulation between the jacket flanges 21.

Detecting apparatus 25 is provided near that portion of the pipe wall which is to be tested for corrosion and includes antenna means 27, a transmitter 29, a receiver and amplifier 31, and a digital computer 33.

The antenna means 27 include a transmitting antenna coil 35, a receiving antenna coil 37 and core means 39. In the preferred embodiment, the transmitting and receiving antenna coils 35, 37 are wound onto the same core means 39, an arrangement which is hereinafter referred to as coincident (see Fig. 3). The core means 39, which is in the shape of a spool, is made of a non-magnetic and non-conductive material such as plastic. The number of turns of the transmitting antenna coil are kept to a minimum to minimize the inductance of the transmitting antenna and to provide for an abrupt switching off of the transmitting antenna coil. In the preferred embodiment, the transmitting antenna coil 35 is made up of 120 turns of 20 to 24 gauge wire. The receiving antenna coil 37 is made up of 400 turns of 34 to 40 gauge wire. The transmitting and receiving antenna coils 35, 37 are connected to the transmitter 29 and receiver 31 by respective pairs of wires 41, 43.

The transmitter 29 which is conventional, generates a train of pulses having magnitudes of 1 to 5 amps. As discussed in more detail below, a plurality of pulses are transmitted for each location of the antenna means 27 for data enhancement purposes. The pulses have abrupt fall times on the order of

10 to 100 microseconds. The pulses of the transmitter pulse train alternate polarity to eliminate dc bias in the instrumentation. The duration of each pulse is sufficiently long to stabilize the pulse magnitude so that there are no induced currents in the pipe wall before the end of the pulse. The transmitter 29 repeats the pulses at a repetition rate that allows all of the necessary data to be obtained for each pulse. For example, a thick pipe wall requires more time to obtain data than does a thinner pipe wall because the induced current takes longer to diffuse in the thick pipe wall. Thus, the repetition rate of pulses will typically be slower for thick pipe walls than for thinner pipe walls.

The receiver and amplifier 31 is a broad band instrument with a wide (5 or 6 orders of magnitude) dynamic range. The receiver 31, which has an A/D converter, samples the signal at a constant rate and integrates the signal over a time window or channel. The duration of the time windows increases with time. The transmitter 29 and the receiver and amplifier 31 are conventional. In practice it has been found that the SIROTEM transmitter, receiver and amplifier unit manufactured by Geoex Pty, Ltd. of Adelaide, Australia, works well. The battery operated SIROTEM unit is portable, a characteristic which allows ease of use when surveying pipelines in the field.

The digital computer 33 is a conventional portable computer with sufficient memory capacity to record the data.

The method of detecting corrosion on a conductive container of the present invention will now be described. As mentioned earlier, the method of the present invention utilizes transient electromagnetic probing (TEMP). TEMP allows the remote probing of a conductor by inducing a current into the conductor and then analyzing the decay of the current.

First, the antenna means 27 is placed on the jacket 19 so as to be in proximity with the near surface 45 of the portion of the pipeline 11 that is to be investigated. Suitable means (not shown) are used to secure the antenna means 27 in position so as to minimize any motion of the antenna means over the investigated pipe wall portion. The transmitting antenna coil 35 is then energized by the transmitter 29 with a pulse. As described above, the transmitting antenna coil 35 is energized for a sufficient period of time to stabilize the pulse magnitude, thereby insuring no eddy currents are induced into the pipeline 11. Then, the transmitting coil 35 is abruptly de-energized by the transmitter by having the pulse fall off rapidly to zero magnitude. This abrupt de-energization of the transmitting antenna coil 35 induces eddy currents into the conductors located near the coil; namely the jacket 19 and the pipe wall 15. The eddy currents, which decay and diffuse away from the antenna means 27 inside of the respective conductors, create a magnetic field that is detected as a time-varying voltage in the receiving antenna coil 37. As soon as the transmitting antenna coil is de-energized, the receiver 31 is then switched on. The receiving antenna coil 37 detects the presence of and the decay of the induced eddy currents in the conductors. The eddy currents are gradually dissipated within the conductors by resistive heat losses. The rate of diffusion is dependent on the conductivity and thickness of the conductor. The receiver 31 samples the signal as detected by the receiving antenna coil 37, whereupon it is amplified to a suitable level and sent to the digital computer 33 for storage and processing. The receiver 31 measures the signal from the time the eddy currents are first induced into the conductors until the signal becomes indistinguishable from noise. The level of noise is reduced by minimizing any motion of the receiving antenna coil 37 relative to the conductors. The received signal is unprocessed data and forms a record in the computer 33 of the decay of the induced currents in the conductors. The transmitting and receiving procedure is repeated many times with the antenna means 27 in the same location to increase the signal-to-noise ratio.

The data is then processed by computer data processing means into a suitable format for interpretation. The first steps in the processing of the data involve the normalization of the received signals and the summing and averaging of the received signals. Because the transmitter 29 in the preferred embodiment is battery operated, the magnitude of the transmitter current is subject to variation. The effects of variation in magnitude in the data are removed by normalizing the received voltage to the transmitted current. The summing and averaging of the received signals for a particular antenna means location serves to increase the signal-to-noise ratio. In particularly noisy environments, as an alternative to summing and averaging, selective stacking can be used to eliminate noisy transients. The result of this initial data processing is a time-varying response curve such as shown in Fig. 4. (Fig. 4 illustrates response curves for various conductors.)

The response curves may be interpreted in accordance with methods which will now be described, with reference to Figs. 4-8d. Referring in particular to Fig. 4, the presence or absence of corrosion on a conductor wall is inferred by examining the shape of the various response curves which have been taken over the area of interest. The shape of each response curve depends in part on the thickness of the conductor wall. For example, the magnitude of the response curve of an infinitely thick conductor wall decays at a fairly

even rate (on a log-log graph), resulting in a fairly straight response curve, whereas the response curve of a conductor having a finite wall thickness begins to break at some point into a more pronounced downward direction than before and decays at a faster rate. This breaking phenomenon is attributed to the induced currents diffusing to and reaching the far surface 47 of the conductor wall. Response curves for thin conductor walls break at earlier times than do response curves for thicker conductor walls.

Because corrosion reduces the thickness of a conductor wall, the presence or absence of corrosion can be inferred by comparing the shape of the response curve for the investigated pipe wall portion to the shape of the response curve for an uncorroded portion of the same type of pipe. For example, in Fig. 4, the two response curves labeled "corrosion" and "no corrosion" are taken from the same pipe. The "no corrosion" response curve is taken from an uncorroded portion of the pipe and is used as a reference, while the "corrosion" response curve is taken from a different portion of the same pipe, which different portion has a pit to simulate corrosion (with the antenna means located at the same distance from the pipe wall, for both response curves). At about 17 ms (milliseconds), the "corrosion" response curve breaks into a more pronounced downward direction and begins to decay at a faster rate than before. The "corrosion" break point occurs at an earlier time than does the "no corrosion" break point (at about 25 ms), indicating that the conductor wall represented by the "corrosion" response curve is thinner than the conductor wall represented by the "no corrosion" response curve.

Referring now to Fig. 5, the "corrosion" and "no corrosion" response curves of Fig. 4 are compared by plotting the ratio of the two curves as a percent response curve, using the "no corrosion" response curve as a reference. The percent response curve highlights the differences between the "corrosion" and the "no corrosion" response curves. By examining the late time portions of the percent response curve (from about 17-20 ms on, which is about when the "corrosion" response curve of Fig. 4 begins to break sharply downward), one can see that the "corrosion" response curve deviates 20 to 30 percent from the "no corrosion" response curve. This 20 to 30 percent difference clearly indicates a difference in wall thickness between the corroded portion of the pipe and the uncorroded portion of the pipe.

In Fig. 4, the response curve labeled "jacket only" is that taken from the metal jacket 19, without the pipe 13. The "jacket only" response curve decays very rapidly so that by the relatively late time of 20 ms, the jacket 19 contributes very little to the total response. This is because the wall thickness of the jacket is much smaller than is the thickness of the pipe wall, so the currents diffuse much more rapidly in the jacket. Thus, for those portions of the "jacket and pipe" response curves that are of interest in locating corrosion (that is the later times), the effect of the jacket can be ignored.

Responses measured near jacket flanges are affected quite strongly by the jacket flanges at all times, as shown in Fig. 7. A response measured near jacket flanges can be corrected to remove the effects of the jacket flanges by normalizing the affected response curve to a reference response curve obtained away from the jacket flanges. As shown in Fig. 7, an effect of the jacket flanges on the response curve is generally parallel shift in a downward direction in the intermediate and late time ranges (later than about 4 ms). That is to say that in the intermediate and late time ranges, the affected response curve is generally parallel to the reference response curves. The affected response curve is corrected by normalizing the affected response curve to the reference response curve in the intermediate time range.

Fig. 7 also serves to illustrate the effect that variations in distance between the antenna means and the pipe wall at one location on the pipe and between the antenna means and the pipe wall at another location on the pipe can have on responses. Such variations in distance result from non-uniform thicknesses of the insulation between the pipe wall and the jacket. Increasing the distance of the antenna means from the pipe wall causes the magnitude of the response to decrease at intermediate and late times, which decrease in magnitude shows up as a generally parallel shift. The responses can be corrected to remove the effects of variations in distance by normalizing the response curves to a reference response curve obtained with the antenna means at some known distance, in the intermediate time range.

The antenna means 27 gives a reading of the average conductor wall thickness over a search area. The size of the search area depends upon antenna size, antenna configuration and the duration of the receiver measuring time after each transmitter pulse. The search area of the antenna means increases with larger antenna sizes or with longer measuring times. In the preferred embodiment, the antenna means 27 has a diameter of about 3 inches (1 inch = 25,40 mm). For a 10.5 inch pipe, the search area is about 12 inches in diameter.

In the usual case, the portion of the pipeline that is to be investigated for corrosion is much larger than the search area of the antenna means. Therefore, a typical pipe survey requires the antenna means to be moved to new locations to

complete the survey. In Figs. 8a through 8d there are shown a corrosion map of a pipe section and corresponding TEMP surveys or profiles along line A-A of the pipe section. In obtaining the TEMP profiles of Figs. 8b through 8d, the antenna means was positioned at various locations along line A-A. In Fig. 8a, the numbers along line 8a indicate ultrasonic point measurements of the wall thickness (in inches) and the shaded areas indicate heavy corrosion, wherein the thickness of the pipe wall is less than for the unshaded areas. The map shows that the pipe wall along line A-A is thickest around 180° and gets thinner moving towards 0° and 360°.

Fig. 8b shows TEMP profiles of the pipe of Fig. 8a along line A-A, without a metal jacket. In Fig. 8b only those values of the response curve at selected discrete instances of time for each antenna means location are plotted. The response curve values at equivalent instances of time are then connected together to form a TEMP profile. Thus, for each antenna means location, the response curve values at time = 8.5 ms, 32.8 ms, 67 ms, 79 ms, 92 ms, and 105 ms are plotted, forming respective TEMP profiles of pipe wall thickness. Each TEMP profile is normalized to the TEMP response obtained over the thickest portion of the pipe. As can be seen in Fig. 8b, the TEMP profiles show that in moving away from 180° in either direction (towards 0° and towards 360°) the pipe wall thickness lessens and is thinnest around 0 to 60° and 320 to 360°. The late time TEMP profiles (67 ms and greater) in particular clearly show the reduced wall thickness, corresponding with the pipe corrosion map of Fig. 8a.

In Fig. 8c, there are shown TEMP profiles of the pipe of Fig. 8a along line A-A, but with a metal jacket. The TEMP profiles of Fig. 8c were obtained in the same manner as the TEMP profiles of Fig. 8b. The jacket flanges, which are located at approximately 95° and 270°, have caused reductions in the amplitudes of the TEMP profile portions near the flanges. The TEMP profiles of Fig. 8c have been corrected to reduce the effects of the jacket flanges by normalizing the responses measured near the jacket flanges to a response measured away from the jacket flanges. The responses are normalized in the intermediate time range (3-6 ms) and the late times (32 ms and greater) are then analyzed. (In Fig. 8d there are shown the TEMP profiles of Fig. 8c before the profiles have been corrected for the effects of the jacket flanges.) There is a good correlation between the TEMP profiles of Fig. 8c and the corrosion map of Fig. 8a. The TEMP profiles of Fig. 8c show that the pipe wall is reduced in thickness around 0 to 60° and 320 to 360°, thus leading to an inference of corrosion at those locations.

Figs. 8a through 8d illustrate an advantageous difference of the TEMP method over the ultrasonic method. The ultrasonic method makes point measurements, requiring a large number of measurements, whereas the antenna means of the TEMP method has a large search area requiring fewer measurements. While the ultrasonic measurements in Fig. 8a are essentially confined to line A-A, the TEMP measurements encompass portions of the pipe extending for a few inches to either side of line A-A. Furthermore, ultrasonic measurements must be made on the bare pipe, while TEMP measurements can be made on the jacket.

For TEMP profiles such as are shown in Figs. 8b-8d, the effects on the responses due to the variations in distance between the antenna means and the pipe wall, which variations are caused by moving the antenna means from one location on the pipe to another location, can be corrected for by creating reference response curves with the antenna means placed at a number of known distances from the pipe wall. The intermediate times of the response curves having distance error are then normalized to the intermediate times of the respective reference response curves.

In Fig. 6, there is shown a TEMP profile of the corrosion pit of Fig. 5. The TEMP profile is obtained by moving the antenna means to a plurality of locations and averaging the responses for the 25 to 52 ms time window at each antenna means location. The physical extent of the corrosion pit is indicated at the bottom left corner of the graph, which shows the pit to have a radius of about 8 inches. The TEMP profile of Fig. 6 shows a good correlation to the physical profile. From about 17 inches on, the TEMP profile shows a slight decrease in magnitude due to the induced currents interacting with the nearby pipe end.

Another method of interpretation of the response curves of Fig. 4 involves examining the time at which the far surface 47 of the pipe wall is initially manifested in the response curve. This time is referred to as the "critical time", and is that point where the response curve begins to break into a more pronounced downward direction than before, as discussed hereinbefore (see Fig. 4). The wall thickness of the pipe is proportional to the square root of the critical time. The constant or factor of proportionality is dependent on the geometry and the conductivity of the pipe, and may be determined by making a determination of the critical time of a particular thickness of the pipe.

The method of the present invention can be used to make quantitative measurements of wall thickness, once the instruments and data have been calibrated on pipes of known thickness and conductivity. Once the actual wall thickness of the investigated pipe is known, comparison to the man-

ufactured wall thickness leads to a determination of wall loss due to corrosion on the investigated pipe.

An important aspect of the present invention is the increased accuracy of detection of corrosion on conductive walls over prior art methods. The present invention operates in the time domain rather than in the frequency domain. In the time domain, all the information needed to probe a conductor wall for accurate detection is obtained with one transmitter pulse. Each pulse contains an infinite number of frequencies. With frequency domain methods however, only a few frequencies are used to probe a conductor wall, resulting in a limited amount of information from which wall thickness is to be determined.

Another important aspect of the present invention is the ability to detect corrosion through insulation. Unlike ultrasonic methods, the present invention does not require the expensive and time consuming task of removing non-conductive and even conductive layers that are positioned between the wall of interest and the probe (the antenna means). Furthermore, the present invention has a greatly expanded search area associated with the antenna means, whereas the ultrasonic method produces essentially point measurements. This difference in probe search areas is of particular importance in detecting corrosion in pipeline walls. Corrosion in pipeline walls becomes hazardous when there is wall loss over a relatively large area. Small spots of corrosion, while generally a nuisance for potential leakages, do not present the explosive hazard that a large corroded area presents. The TEMP method is more efficient in detecting hazardous pipeline wall loss by giving an average measurement over the antenna means search area.

Although the method of the present invention has been described for use in detecting corrosion on pipelines, the method may also be used to detect corrosion on the electrically conductive walls of other types of container means such as storage vessels and pressure vessels. In addition, the method of the present invention can be used on uninsulated as well as insulated container means.

The antenna means can have the transmitting antenna and receiving antenna configured in arrangements other than the coincident arrangement described herein. One such arrangement has the transmitting antenna separate but coplanar with the receiving antenna. Another arrangement has a plurality of receiving antennas located within a large transmitting antenna loop.

Although this invention has been described with a certain degree of particularity, it is understood that the present disclosure is made only by way of example and that numerous changes in the details of methods may be resorted to without departing from the scope of the invention, as defined in the appended claims.

Claims

1. A method of measuring wall thickness of container means (for example to detect irregularities such as corrosion) said wall (15) being electrically conductive and having a near surface (45) and a far surface (47), comprising the steps of placing transmitting antenna means and receiving antenna means (27) in proximity with the near surface of that portion of the container means wall (15) which is to be investigated for corrosion; inducing a transient eddy current into the container means wall portion by means of the transmitting antenna means; and characterised by

   a. receiving a signal indicative of said induced current in said container means wall portion with the receiving antenna means; and

   b. comparing the decay of the received signal over a period of time with a reference decay indicative of a known wall thickness, whereby the thickness of the the container means wall portion can be inferred.

2. The method of Claim 1 wherein a record is created of the decay of a said received signal, said record being compared with a reference decay record obtained from a container means of known wall thickness.

3. The method of Claim 1 or Claim 2, wherein said transmitting antenna means and said receiving antenna means (27) are placed adjacent a layer of insulation (17) that is adjacent said container means wall (15) such that the insulation is interposed between said container means wall and said transmitting antenna means and said receiving antenna means, wherein said method can be performed with said insulation remaining intact on said container means.

4. The method of any preceding claim, wherein said transmitting antenna means and said receiving antenna means (27) are placed adjacent a conductive jacket (19) that is adjacent said container means wall such that said jacket is interposed between said container means wall and said transmitting antenna means and said receiving antenna means, said jacket having a wall thickness substantially less that the wall thickness of said container means, said method being performed with said jacket remaining intact on said container means.

5. The method of Claim 2 and any other preceding claim, wherein said record from said investigated container means wall portion and said reference records have respective portions where the rate of decay changes from a relatively constant rate of decay in the log/log domain to an accelerating rate of decay, further comprising the step of interpreting said record for an indication of the thickness of said investigated container means wall portion by comparing the accelerating rate of decay portion of said record with the accelerating rate of decay portions of said reference records, wherein if the accelerating rate of decay portion of said record decays faster than the accelerating rate of decay portions of said reference records then the wall thickness of said investigated container means wall portion is less than the wall thickness of said reference records.

6. The method of Claim 5, wherein said jacket (19) is provided in portions, with said jacket portions having joint means (21) for joining said jacket portions together, with said joint means having an effect on the decay of said received signal, further comprising the step of correcting the record of the decay of said received signal for the effects of said joint means by normalizing said record to said reference record over those portions of the records where said records are generally parallel, said reference record being created as a record of the decay of a received signal indicative of a similarly induced current in a portion of a substantially similar container means wall that is located some distance away from joint means such that said reference record is unaffected by joint means.

7. The method of Claim 4, wherein said insulation (17) has a non-uniform thickness causing variations in the distance between the transmitting antenna means and the receiving antenna means (27) and the container means wall (15) at said investigated portion and between the transmitting antenna means and the receiving antenna means and the container means wall at a second investigated portion with said variations in distance having an effect on the decay of said received signal, further comprising the step of correcting the record of the decay of said received signal for the effects of said variations in distance by normalizing said record to said reference record over those portions of the records where said records are generally parallel, said reference record being created with said transmitting antenna means and said receiving antenna means located at known distances from said conductor means wall portion.

8. The method of Claim 2 and any other preceding claim, further comprising the step of determining the time in said record that said induced current reaches the far surface (47) of the investigated container means wall portion, whereby the thickness of said investigated container means wall portion (15) is indicated.

9. The method of Claim 2 and any other preceding claim, further comprising the steps of:
   a. keeping the transmitting and receiving antenna means (27) in the same location and creating a plurality of records of the decay of received signals indicative of similarly induced currents for that transmitting and receiving antenna means location.
   b. processing said plurality of records to increase the signal to noise ratio for the transmitting and receiving antenna means location.

10. The method of Claim 1, wherein the received signal decays into noise over a period of time, and wherein the decay of the received signal during intermediate and late time ranges within said period is compared with a reference decay of a second received signal obtained from another container means wall portion of known thickness, wherein said first received signal decay from said investigated container means wall portion (15) gives an indication of the thickness of the investigated container means wall portion.

11. The method of Claim 1 wherein the received signal decays into noise over of a period of time, and wherein the decay of the received signal during intermediate and late time ranges within that period is compared with the corresponding decays of received signals indicative of induced currents induced in the same manner in other portions of the container means walls, and comparing the decay of said first received signal to the decays of said other received signals wherein the decay of the first received signal gives an indication of the thickness of the investigated container means wall portion relative to the other portions of the container means wall.

12. The method of Claim 10 or 11 wherein each of said received signals has a portion where the rate of decay changes from a relatively constant rate of decay in the log/log domain to an

accelerating rate of decay, further comprising the step of comparing the accelerating rate of decay portion of the first received signal to the accelerating rate of decay portions of the other received signals, wherein if the accelerated rate of decay portions of said first received signal decay faster than the accelerating rate of decay portions of said other received signals then the wall thickness of said investigated container means wall portion is less than the wall thickness of said other container means wall portion.

13. The method of any one of Claims 10 to 12 wherein said transmitting antenna means and said receiving antenna means (27) comprise a coincident antenna arrangement (35, 37).

14. The method of Claim 1 wherein the received signal decays into noise over a period of time, and wherein the decay of the first received signal during intermediate and late time ranges within said period is compared with the decay of a reference signal obtained from a reference container means with a known wall thickness.

15. The method of Claim 14 wherein each of said first and reference received signals has a portion where the rate of decay changes from a relatively constant rate of decay in the log/log domain to an accelerating rate of decay, further comprising the step of comparing the accelerating rate of decay portion of the first received signal to the accelerating rate of decay portion of the reference received signal, wherein if the accelerated rate of decay portion of said first received signal decays faster than the accelerated rate of decay portion of said reference received signal then the wall thickness of said investigated container wall means wall portion is less than the wall thickness of said reference container means wall portion.

16. The method of Claim 1, wherein the received signal decays into noise over a period of time during which there are intermediate and late time ranges, and a critical time at which the rate of decay of said received signal changes from a relatively constant rate of decay in the log/log domain to an accelerating rate of decay the method comprising examining the received signal to determine the critical time, determining a factor of proportionality between the wall thickness of said investigated container means wall portion and the critical time by examining the critical times of reference decays, said reference decays being obtained from a reference container means having known wall thicknesses; and determining the thickness of said investigated container means wall portion by applying said factor of proportionality to the square root of the critical time.

17. The method of any one of Claims 10 to 16 wherein the said container means wall (15) is provided with a layer of insulation (17), said insulation being located adjacent to said container means wall (15) so as to be interposed between said container means wall portion and said transmitting antenna means and said receiving antenna means (27), wherein said transmitting antenna means induces current into the investigated container means wall portion through said insulation and said receiving antenna means detects said induced current through said insulation.

18. The method of Claim 17 wherein said insulation has a non-uniform thickness causing variations in the distance between the transmitting antenna means and the receiving antenna means and the container means wall at said investigated portion and between the transmitting antenna means and the receiving antenna means and the container means wall at a second investigated portion with said variations in distance having an effect on the decay of said induced current in said container means wall portion, further comprising the step of correcting the first received signal for the effects of said variations in distance by normalizing the first received signal to said reference decay over the intermediate time ranges of said decay periods, said reference decay being created with the transmitting antenna means and the receiving antenna means located at known distances from the container means wall portion.

19. The method of one of Claims 10 to 18, wherein said container means wall is provided with a layer of insulation (17) and a conductive jacket (19), said insulation and said jacket being located adjacent to said container means wall (15) such that said insulation is interposed between said container means wall and said jacket, said jacket being interposed between said insulation and said transmitting antenna means receiving antenna means (27), wherein said transmitting antenna means induces current into the container means wall portion through said insulation and said jacket and said receiving antenna means detects said induced current through said insulation and said jacket.

20. The method of Claim 19 wherein said jacket is provided in portions, with said jacket portions having seam means (21) for joining said jacket portions together, with said seam means having an effect on the decay of said induced current in said container means wall portion, further comprising the step of

correcting the first received signal for the effects of said seams means by normalizing the first received signal to said reference decay over the intermediate time ranges of said decay periods, said reference decay being created with the transmitting antenna means and the receiving antenna means (27) located some distance away from a seam means on a container means such that the reference decay is unaffected by said seam means.

Patentansprüche

1. Eine Methode zum Messen der Wanddicke von Behältermitteln (zum Beispiel zur Feststellung von Unregelmäßigkeiten wie Korrosion), wobei die besagte Wand (15) elektrisch leitend ist und eine zugewandte Oberfläche (45) und eine abgewandte Oberfläche (47) hat; diese Methode besteht aus den Schritten, ein Sendeantennenmittel und ein Empfangsantennenmittel (27) nahe der zugewandten Oberfläche des auf Korrosion zu untersuchenden Teils der Behältermittelwand (15) aufzustellen und mit dem Sendeantennenmittel einen transienten Wirbelstrom in den Behältermittelwandteil zu induzieren, und ist gekennzeichnet durch:

a. Empfang eines Signals mit dem Empfangsantennenmittel, das den in den besagten Behältermittelwandteil induzierten Strom anzeigt; und

b. Vergleich des Abklingens des empfangenen Signals über einen Zeitraum mit einer eine bekannte Wanddicke anzeigenden Bezugsabklingung, woraus die Dicke des Behältermittelwandteils gefolgert werden kann.

2. Die Methode von Anspruch 1, bei welcher das Abklingen des besagten empfangenen Signals registriert und die besagte Registrierung mit einer Bezugsabklingregistrierung verglichen wird, die von einem Behältermittel mit bekannter Wanddicke erhalten wurde.

3. Die Methode von Anspruch 1 oder Anspruch 2, bei welcher das besagte Sendeantennenmittel und das besagte Empfangsantennenmittel (27) neben einer Dämmschicht (17) aufgestellt werden, die sich neben der besagten Behältermittelwand (15) befindet, und zwar derart, daß die Dämmschicht zwischen der besagten Behältermittelwand und dem besagten Sendeantennenmittel und dem besagtem Empfangsantennenmittel liegt, bei welcher die besagte Methode durchgeführt werden kann, während die besagte Dämmschicht intakt auf dem besagten Behältermittel bleibt.

4. Die Methode eines der vorhergehenden Ansprüche, bei welcher das besagte Sendeantennenmittel und das besagte Empfangsantennenmittel (27) neben einem leitfähigen Mantel (19) aufgestellt werden, der sich neben der besagten Behältermittelwand befindet, und zwar derart, daß der besagte Mantel zwischen der besagten Behältermittelwand und dem besagten Sendeantennenmittel und dem besagten Empfangsantennenmittel liegt, wobei der besagte Mantel eine Wanddicke hat, die wesentlich geringer als die Wanddicke des besagten Behältermittels ist; die besagte Methode wird durchgeführt, während der besagte Mantel intakt auf dem besagten Behältermittel bleibt.

5. Die Methode von Anspruch 2 und eines der vorhergehenden Ansprüche, bei welcher die besagte Registrierung über den besagten untersuchten Behältermittelwandteil und die besagten Bezugsregistrierungen jeweils Teile haben, bei denen die Abklinggeschwindigkeit sich von einer relativ konstanten Abklinggeschwindigkeit im log/log Bereich auf eine sich beschleunigende Abklinggeschwindigkeit ändert; diese Methode umfaßt als weiteren Schritt die Auslegung der besagten Registrierung, um durch einen Vergleich des Teils der besagten Registrierung mit sich beschleunigender Abklinggeschwindigkeit mit den Teilen der Bezugsregistrierungen mit sich beschleunigender Abklinggeschwindigkeit einen Hinweis auf die Dicke des besagten untersuchten Behältermittelwandteils zu erhalten; bei dieser Methode ist, wenn der Teil der besagten Registrierung mit sich beschleunigender Abklinggeschwindkeit schneller als die Teile der besagten Bezugsregistrierungen mit sich beschleunigender Abklinggeschwindigkeit abklingen, die Wanddicke des besagten Behältermittelwandteils geringer als die Wanddicke der besagten Bezugsregistrierungen.

6. Die Methode von Anspruch 5, bei welcher der besagte Mantel (19) in Teilen bereitgestellt wird, welche besagten Mantelteile Nahtmittel (21) zur Verbindung der Mantelteile miteinander haben, und welche besagten Nahtmittel eine Auswirkung auf das Abklingen des besagten empfangenen Signals haben; diese Metho-

de umfaßt als weiteren Schritt die Berichtigung der Registrierung des Abklingens des besagten empfangenen Signals im Hinblick auf die Auswirkungen der besagten Nahtmittel, indem die besagten Registrierungen zu der besagten Bezugsregistrierung bei den Teilen der Registrierungen, bei denen die besagten Registrierungen im allgemeinen parallel sind, normalisiert werden, wobei die besagte Bezugsregistrierung als eine Registrierung des Abklingens eines empfangenen Signals erzeugt wird, das einen Strom anzeigt, der auf ähnliche Weise in einen Teil einer im wesentlichen ähnlichen Behältermittelwand induziert wird, die sich in einigem Abstand auf eine Weise von dem Nahtmittel befindet, daß die besagte Bezugsregistrierung von dem Nahtmittel unbeeinträchtigt bleibt.

7. Die Methode von Anspruch 4, bei welcher die besagte Dämmschicht (17) eine uneinheitliche Dicke hat und dadurch unterschiedliche Abstände zwischen dem Sendeantennenmittel und dem Empfangsantennenmittel (27) und der Behältermittelwand (15) an dem besagten untersuchten Teil sowie zwischen dem Sendeantennenmittel und dem Empfangsantennenmittel und der Behältermittelwand bei einem zweiten untersuchten Teil verursacht, wobei die besagten unterschiedlichen Abstände eine Auswirkung auf das Abklingen des besagten empfangenen Signals haben; diese Methode umfaßt als weiteren Schritt die Berichtigung der Registrierung des Abklingens des besagten empfangenen Signals im Hinblick auf die besagten unterschiedlichen Abstände, indem die besagte Registrierung zu der besagten Bezugsregistrierung bei den Teilen der Registrierungen, bei denen die Registrierungen im allgemeinen parallel sind, normalisiert wird, wobei die besagte Bezugsregistrierung erzeugt wird, während sich das besagte Sendeantennenmittel und das besagte Empfangsantennenmittel in bekanntem Abstand von dem besagten Behältermittelwandteil befinden.

8. Die Methode von Anspruch 2 und einem der vorhergehenden Ansprüche, die des weiteren den Schritt umfaßt, den Zeitpunkt bei der besagten Registrierung festzustellen, an dem der besagte induzierte Strom die abgewandte Oberfläche (47) des untersuchten Behältermittelwandteils erreicht, wodurch die Dicke des besagten Behältermittelwandteils (15) angezeigt wird.

9. Die Methode von Anspruch 2 und einem der vorhergehenden Ansprüche, die die folgenden weiteren Schritte umfaßt:

a. Das Sende- und Empfangsantennenmittel (27) am gleichen Standort behalten und eine Pluralität von Registrierungen des Abklingens von empfangenen Signalen erzeugen, die auf ähnliche Weise induzierten Strom für diesen Standort des Sende- und Empfangsantennenmittels anzeigen.

b. Bearbeitung der besagten Pluralität von Registrierungen zur Erhöhung des Signal-Geräusch-Verhältnisses für den Standort des Sende- und Empfangsantennenmittels.

10. Die Methode von Anspruch 1, bei welcher das empfangene Signal über einen Zeitraum in Geräusch abklingt, und bei welcher das Abklingen des empfangenen Signals während des mittleren und späten Zeitbereichs innerhalb des besagten Zeitraums mit einem Bezugsabklingen eines zweiten empfangenen Signals verglichen wird, das von einem anderen Behältermittelwandteil von bekannter Dicke erhalten wurde; bei dieser Methode zeigt das Abklingen des von dem besagten untersuchten Behältermittelwandteil (15) empfangenen ersten Signals die Dicke des untersuchten Behältermittelwandteils an.

11. Die Methode von Anspruch 1, bei welcher das empfangene Signal über einen Zeitraum in Geräusch abklingt, und bei welcher das Abklingen des empfangenen Signals während des mittleren und späten Zeibereichs innerhalb des besagten Zeitraums mit dem entsprechenden Abklingen von empfangenen Signalen verglichen wird, die den auf gleiche Weise in andere Teile der Behältermittelwand induzierten Strom anzeigen, und Vergleich des Abklingens des besagten ersten empfangenen Signals mit dem Abklingen der besagten anderen empfangenen Signale; bei dieser Methode zeigt das Abklingen des ersten empfangenen Signals die Dikke des untersuchten Behältermittelwandteils im Verhältnis zu den anderen Teilen der Behältermittelwand an.

12. Die Methode von Anspruch 10 oder 11, bei welcher jedes der besagten empfangenen Signale einen Teil hat, bei dem die Abklinggeschwindigkeit sich von einer relativ kostanten Abklinggeschwindigkeit im log/log-Bereich auf eine sich beschleunigende Abklinggeschwindigkeit ändert; bei dieser Methode, die als weiteren Schritt den Vergleich des Teils mit sich beschleunigendem Anklingen des ersten empfangenen Signals mit den Teilen mit sich beschleunigendem Abklingen der anderen empfangenden Signale umfaßt, ist, wenn der

Teil mit sich beschleunigendem Abklingen des besagten ersten empfangenen Signals schneller abklingt als die Teile mit sich beschleunigendem Abklingen der besagten anderen empfangenen Signale, die Wanddicke des besagten untersuchten Behältermittelwandteils geringer als die Wanddicke des besagten anderen Behältermittelwandteils.

13. Die Methode eines der Ansprüche 10 bis 12, bei welcher das besagte Sendeantennenmittel und das besagte Empfangsantennenmittel (27) aus einer koinzidenten Antennenanordnung bestehen (35, 37).

14. Die Methode von Anspruch 1, bei welcher das empfangene Signal über einen Zeitraum in Geräusch abklingt, und bei welcher das Abklingen des ersten empfangenen Signals während des mittleren und späten Zeitbereichs innerhalb des besagten Zeitraums mit dem Abklingen eines Bezugssignals verglichen wird, das von einem Bezugsbehältermittel mit bekannter Wanddicke erhalten wurde.

15. Die Methode von Anspruch 14, bei welcher das besagte erste empfangene Signal und das besagte empfangene Bezugssignal jeweils einen Teil haben, bei dem die Abklinggeschwindigkeit sich von einer relativ konstanten Abklinggeschwindigkeit im log/log Bereich auf eine sich beschleunigende Abklinggeschwindigkeit ändert; bei dieser Methode, die als weiteren Schritt den Vergleich des Teils mit sich beschleunigender Abklinggeschwindigkeit des ersten empfangenen Signals mit dem Teil mit sich beschleunigender Abklinggeschwindigkeit des empfangenen Bezugssignals umfaßt, ist, wenn der Teil mit sich beschleunigender Abklinggeschwindigkeit des ersten empfangenen Signals schneller abklingt als der Teil mit sich beschleunigender Abklinggeschwindigkeit des besagten empfangenen Bezugssignals, die Wanddicke des besagten untersuchten Behältermittelwandteils geringer als die Wanddicke der besagten Bezugsbehältermittelwand.

16. Die Methode von Anspruch 1, bei welcher das empfangene Signal über einen Zeitraum, in dem sich ein mittlerer und später Zeitbereich und eine kritische Zeit befindet, in der die Abklinggeschwindigkeit des besagten empfangenen Signals sich von einer relativ konstanten Abklinggeschwindigkeit im log/log Bereich auf eine sich beschleunigende Abklinggeschwindigkeit ändert; diese Methode umfaßt die Untersuchung des empfangenen Signals zur Feststellung der kritischen Zeit, die Feststellung eines Proportionalitätsfaktors zwischen der Wanddicke des besagten untersuchten Behältermittelwankdteils und der kritischen Zeit durch Untersuchung der kritischen Zeiten von Bezugsabklingungen, wobei die besagten Bezugsabklingungen von einem Bezugsbehältermittel mit bekannter Wanddicke erhalten werden, sowie die Feststellung der Dicke des besagten untersuchten Behältermittelwandteils durch Anwendung des besagten Proportionalitätsfaktors auf die Quadratwurzel der kritischen Zeit.

17. Die Methode eines der Ansprüche 10 bis 16, bei welcher die besagte Behältermittelwand (15) eine Dämmschicht (17) erhält, wobei die besagte Dämmschicht sich derart neben der besagten Behältermittelwand (15) befindet, daß sie zwischen dem besagten Behältermittelwandteil und dem besagten Sendeantennenmittel und dem besagten Empfangsantennenmittel (27) liegt; bei dieser Methode induziert das besagte Sendeantennenmittel in den untersuchten Behältermittelwandteil durch die besagte Dämmschicht einen Strom, und das besagte Empfangsantennenmittel stellt den besagten induzierten Strom durch die besagte Dämmschicht fest.

18. Die Methode von Anspruch 17, bei welcher die besagte Dämmschicht eine uneinheitliche Dikke hat und unterschiedliche Abstände zwischen dem Sendeantennenmittel und dem Empfangsantennenmittel und der Behältermittelwand bei dem besagten untersuchten Teil sowie zwischen dem Sendeantennenmittel und dem Empfangsantennenmittel und der Behältermittelwand bei einem zweiten untersuchten Teil verursacht, wobei die besagten unterschiedlichen Abstände eine Auswirkung auf das Abklingen des in den besagten Behältermittelwandteil induzierten Stroms haben; diese Methode umfaßt als weiteren Schritt die Berichtigung des ersten empfangenen Signals im Hinblick auf die Auswirkungen der besagten unterschiedlichen Abstände, indem das erste empfangene Signal zu dem besagten Bezugsabklingen während der mittleren Zeitbereiche der besagten Abklingzeiträume normalisiert wird, wobei das besagte Bezugsabklingen erzeugt wird, während das Sendeantennenmittel und das Empfangsantennenmittel sich in bekannten Abständen vom Behältermittelwandteil befinden.

19. Die Methode eines der Ansprüche 10 bis 18, bei welcher die besagte Behältermittelwand

eine Dämmschicht (17) und einen leitenden Mantel (19) erhält, wobei der besagte Mantel sich derart neben der besagten Behältermittelwand (15) befindet, daß die besagte Dämmschicht zwischen der besagten Behältermittelwand und dem besagten Mantel liegt und der besagte Mantel zwischen der besagten Dämmschicht und dem besagten Sendeantennenmittel und dem besagten Empfangsantennenmittel (27) liegt; bei dieser Methode induziert das besagte Sendeantennenmittel in den Behältermittelwandteil durch die besagte Dämmschicht und den besagten Mantel einen Strom, und das besagte Empfangsantennenmittel stellt den besagten induzierten Strom durch die besagte Dämmschicht und den besagten Mantel fest.

20. Die Methode von Anspruch 19, bei welcher der besagte Mantel in Teilen bereitgestellt wird, wobei die besagten Mantelteile Nahtmittel (21) zur Verbindung der besagten Mantelteile miteinander haben und die besagten Nahtmittel eine Auswirkung auf das Abklingen des in den besagten Behältermitelwandteils induzierten Stroms haben; diese Methode umfaßt des weiteren den Schritt,

das erste empfangene Signal im Hinblick auf die Auswirkungen der besagten Nahtmittel zu berichtigen, indem das erste empfangene Signal zu dem besagten Bezugsabklingen über die mittleren Zeitbereiche der besagten Abklingzeiträume normalisiert wird, wobei das besagte Bezugsabklingen erzeugt wird, während das Sendeantennenmittel und das Empfangsantennenmittel (27) sich derart im Abstand von einem Nahtmittel eines Behältermittels befinden, daß das Bezugsabklingen von dem besagten Nahtmittel nicht beeinträchtigt wird.

Revendications

1. Une méthode de mesure de l'épaisseur d'une paroi d'un récipient (par exemple en vue de détecter des irrégularités telles que la corrosion), ladite paroi (15) étant conductrice de l'électricité et ayant une surface proche (45) et une surface opposée (47), comportant les étapes suivantes: le placement d'un objet servant d'antenne émettrice et d'un objet servant d'antenne de réception (27) à proximité de la surface proche de la portion de la paroi du récipient faisant l'objet d'un examen de corrosion; la création d'un tourbillon de courant induit transitoire dans ladite portion de la paroi du récipient au moyen de l'objet servant d'antenne émettrice; et caractérisée par:

a. la réception d'un signal indicatif dudit courant induit dans ladite portion de paroi du récipient su moyen de l'objet servant d'antenne de réception, et

b. la comparaison de la dégradation du signal reçu au bout d'un certain temps avec une dégradation de référence indicative d'une épaisseur de paroi connue, à partir de laquelle il est possible d'inférer l'épaisseur de la portion de paroi du récipient.

2. La méthode utilisée dans la déclaration 1 par laquelle il est créé un enregistrement de la dégradation d'un signal donné, ledit enregistrement étant comparé avec un enregistrement de dégradation de référence obtenu à partir d'un récipient dont l'épaisseur de la paroi est connue.

3. La méthode utilisée dans la déclaration 1 ou la déclaration 2, par laquelle ledit objet servant d'antenne d'émission et ledit objet servant d'antenne de réception (27) sont placés de façon à être adjacents à une couche isolante (17), elle-même adjacente à ladite paroi de récipient (15), de telle manière que la couche isolante soit interposée entre ladite paroi de récipient et ledit objet servant d'antenne émettrice et ledit objet servant d'antenne de réception.

4. La méthode par laquelle dans toute déclaration précédente ledit objet servant d'antenne émettrice et ledit objet servant d'antenne de réception sont placés de manière à être adjacents à une enveloppe conductrice (19) qui est adjacente à ladite paroi du récipient de telle sorte que l'enveloppe protectrice est interposée entre ladite paroi de récipient et ledit objet servant d'antenne émettrice et ledit objet servant d'antenne de réception, ladite enveloppe ayant une épaisseur de paroi très inférieure à l'épaisseur de la paroi du récipient, et par laquelle cette action peut être exécutée de telle façon que la dite enveloppe protectrice reste intacte sur ledit récipient.

5. La méthode utilisée dans la déclaration 2 ou une déclaration précédente, par laquelle ledit enregistrement relatif à ladite portion de paroi d'un récipient faisant l'objet d'un examen et ledit enregistrement de référence ont respectivement des portions dans lesquelles le taux de dégradation change dans le domaine log/log, étant au départ un taux de dégradation relativement constant, pour devenir un taux de dégradation accéléré et par laquelle la méthode comporte une étape d'interprétation dudit enre-

gistrement pour une indication de l'épaisseur de ladite portion de paroi de récipient faisant l'objet d'un examen, en comparant la portion de dégradation accélérée dudit enregistrement à la portion de dégradation accélérée dudit enregistrement de référence, et par laquelle si la portion dudit enregistrement faisant ressortir un taux de dégradation accéléré se dégrade plus rapidement que ledit enregistrement de référence, il s'ensuit que l'épaisseur de paroi de ladite portion de paroi de récipient faisant l'objet d'un examen est moindre que l'épaisseur de paroi correspondant au dit enregistrement de référence.

6. La méthode dans laquelle, dans la déclaration 5, ladite enveloppe est fournie en portions et lesdites portions d'enveloppe sont munies de moyens de jonction (21) afin de joindre ensemble lesdites portions d'enveloppe, lesquels moyens de jonction ont un effet sur la dégradation dudit signal reçu, et la méthode comprend en outre l'étape de correction de l'enregistrement de la dégradation dudit signal reçu afin de tenir compte de l'effet desdits moyens de jonction en normalisant ledit enregistrement par rapport à l'enregistrement de référence sur les portions de ces enregistrements où ces enregistrements sont généralement parallèles, ledit enregistrement de référence étant créé comme un enregistrement de la dégradation d'un signal reçu indicatif d'un courant induit créé de la même façon dans une portion de paroi d'un récipient substantiellement similaire située à une certaine distance de moyens de jonction, de telle façon que ledit enregistrement de référence ne soit pas affecté par les moyens de jonction.

7. La méthode, dans la déclaration 4, par laquelle la couche isolante (17) a une épaisseur non uniforme, causant des variations entre la distance de l'objet servant d'antenne d'émission et de l'objet servant d'antenne de réception à ladite paroi de récipient (15) à l'emplacement de la portion faisant l'objet d'un examen et la distance de l'objet servant d'antenne d'émission et de l'objet servant d'antenne de réception à ladite paroi de récipient (15) à l'emplacement d'une deuxième portion faisant l'objet d'un examen, ces variations de distance ayant un effet sur la dégradation dudit signal reçu, et comportant en outre l'étape de correction de l'enregistrement de la dégradation dudit signal reçu, pour tenir compte des effets de ces variations de distance en normalisant lesdits enregistrements par rapport aux dits enregistrements de référence sur les portions de ces enregistrements où ces enregistrements sont généralement parallèles, lesdits enregistrements étant créés au moyen dudit objet servant d'antenne d'émission et dudit objet servant d'antenne de réception placés à des distances connues de ladite portion de paroi conductrice.

8. La méthode de la déclaration 2 et de toute autre déclaration précédente comprenant en outre l'étape de détermination dans ledit enregistrement du temps pris par ledit courant induit pour atteindre la surface opposée (47) de la portion de paroi du récipient faisant l'objet d'un examen, lequel temps indique l'épaisseur de ladite portion de paroi du récipient (15).

9. La méthode de la déclaration 2 et de toute déclaration précédente comportant en outre les étapes suivantes:

   a. laisser les objets servant d'antennes d'émission et de réception (27) au même emplacement et créer une pluralité d'enregistrements de la dégradation du signal reçu, indicatifs de courants induits créés de la même façon à cet emplacement des objets servant d'antennes.

   b. le traîtement de ladite pluralité d'enregistrements de manière à augmenter le rapport signal/bruit à l'emplacement des objets servant d'antennes d'émission et de réception.

10. La méthode de la déclaration 1 dans laquelle le signal reçu se dégrade en bruit au bout d'un certain temps et par laquelle la dégradation du signal reçu durant les périodes intermédiaires et tardives dans le cadre dudit temps est comparée à une dégradation de référence d'un deuxième signal reçu obtenu sur une autre portion de paroi de récipient d'épaisseur connue et par laquelle la première dégradation du signal reçu de ladite portion de paroi de récipient (15) donne une indication de l'épaisseur de la portion de paroi du récipient faisant l'objet d'un examen.

11. La méthode de la réclamation 1 dans laquelle le signal reçu se dégrade en bruit au bout d'un certain temps et par laquelle la dégradation dudit signal durant les périodes intermédiaires et tardives dans le cadre de ce temps est comparée aux dégradations correspondantes des signaux reçus indicatifs de courants induits créés de la même façon dans d'autres portions de paroi du récipient, et par laquelle la dégradation du premier signal est comparée à la dégradation desdits autres signaux reçus et où la dégradation du premier signal reçu

donne une indication de l'épaisseur de la portion de paroi du récipient faisant l'objet d'un examen par rapport aux autres portions de paroi du récipient.

12. La méthode des déclarations 10 et 11 dans laquelle chacun desdits signaux reçus comporte une portion dans laquelle le taux de dégradation change, passant d'un taux relativement constant dans le domaine log/log à un taux de dégradation accéléré et comportant l'étape qui consiste à comparer la portion de taux de dégradation accéléré du premier signal reçu à la portion de taux de dégradation accéléré des autres signaux reçus et dans laquelle, si les portions de dégradation accélérée du premier signal reçu indiquent une dégradation plus rapide que les portions de dégradation accélérée des autres signaux reçus, il s'ensuit que l'épaisseur de la portion de paroi du récipient faisant l'objet d'un examen est moindre que l'épaisseur de ladite autre portion de paroi du récipient.

13. La méthode de n'importe laquelle des déclarations 10 à 12 par laquelle ledit objet servant d'antenne d'émission et ledit objet servant d'antenne de réception (27) font l'objet d'une disposition ayant pour but la coïncidence des antennes (35, 37).

14. La méthode de la déclaration 1 par laquelle le premier signal reçu se dégrade en bruit au bout d'un certain temps et par laquelle la dégradation du premier signal reçu durant les périodes intermédiaires et tardives dans le cadre de ce temps est comparée à la dégradation d'un signal de référence obtenu à partir d'une portion de paroi de récipient ayant une épaisseur connue.

15. La méthode de la déclaration 14, par laquelle chacun des premiers signaux reçus et des signaux de référence reçus comporte une portion dans laquelle le taux de dégradation change, passant d'un taux de dégradation relativement constant dans le domaine log/log à un taux de dégradation accéléré, la méthode comportant en outre une étape de comparaison de la portion à taux de dégradation accéléré dudit premier signal reçu et de la portion à taux de dégradation accéléré du signal de référence reçu, au cours de laquelle, si la portion à taux de dégradation accéléré dudit premier signal reçu se dégrade plus rapidement que la portion à taux de dégradation accéléré dudit signal de référence il s'ensuit que l'épaisseur de paroi de ladite portion de paroi du récipient est moindre que l'épaisseur de paroi de ladite portion de paroi du récipient de référence.

16. La méthode de la déclaration 1, par laquelle le signal reçu se dégrade en bruit au bout d'un certain temps, durant lequel il y a des périodes intermédiaires et tardives, ainsi qu'un moment critique auquel le taux de dégradation change pour passer d'un taux de dégradation relativement constant à un taux de dégradation accéléré, la méthode comportant l'examen du signal reçu afin de déterminer le temps critique, la détermination d'un facteur de proportionnalité entre l'épaisseur de paroi de la portion de paroi de récipient faisant l'objet d'un examen et le temps critique en examinant le temps critique de dégradations de référence, les dites dégradations de référence étant obtenues à partir d'un récipient de référence dont l'épaisseur des parois est connue, et la détermination de l'épaisseur de ladite portion de paroi de récipient en appliquant ledit facteur de proportionnalité à la racine carrée du temps critique.

17. La méthode de l'une quelconque des déclarations 10 à 16 par laquelle ladite paroi de récipient est garnie d'une couche isolante (17), ladite couche isolante étant adjacente à ladite paroi de récipient (15) de manière à être interposée entre la dite portion de paroi du récipient et ledit objet servant d'antenne émettrice et ledit objet servant d'antenne de réception (27), et par laquelle ledit objet servant d'antenne émettrice produit un courant induit dans la portion de paroi de récipient faisant l'objet d'un examen à travers ladite couche isolante et ledit objet servant d'antenne de réception détecte ledit courant induit à travers ladite couche isolante.

18. La méthode de la déclaration 17 par laquelle ladite couche isolante a une épaisseur non uniforme causant des variations entre les distances de l'objet servant d'antenne émettrice et de l'objet servant d'antenne de réception à la paroi de récipient à l'emplacement de ladite portion faisant l'objet d'un examen et de l'objet servant d'antenne émettrice et de l'objet servant d'antenne de réception à la paroi de récipient à l'emplacement d'une deuxième portion faisant l'objet d'un examen, lesdites variations de distance ayant un effet sur la dégradation dudit courant induit dans ladite portion de paroi de récipient, et comprenant en outre l'étape de correction du signal reçu en premier à l'égard des effets desdites variations de distance, laquelle correction est effectuée en normalisant le premier signal reçu par rapport à la dégra-

dation de référence sur les périodes intermédiaires de ladite période de dégradation, ladite dégradation de référence étant créée au moyen de l'objet servant d'antenne émettrice et de l'objet servant d'antenne de réception placés à des distances connues de la portion de paroi de récipient.

19. La méthode de l'une des déclarations 10 à 18 par laquelle lesdites parois de récipient sont garnies d'une couche isolante (17) et d'une enveloppe conductrice (19), ladite couche isolante et ladite enveloppe étant adjacentes à ladite paroi de récipient (15) de telle façon que ladite couche isolante est interposée entre ladite paroi de récipient et ladite enveloppe et que ladite enveloppe est interposée entre ladite couche isolante et ledit objet servant d'antenne émettrice objet servant d'antenne de réception (27), et où ledit objet servant d'antenne émettrice produit un courant induit dans la portion de paroi de récipient à travers ladite couche isolante et ladite enveloppe, et l'objet servant d'antenne de réception détecte ledit courant induit à travers ladite couche isolante et ladite enveloppe.

20. La méthode de la déclaration 20 par laquelle ladite enveloppe est fournie en portions, lesdites portions étant munies de moyens de jointure (21) afin de joindre lesdites portions d'enveloppe ensemble, lesquels moyens de jointure ont un effet sur la dégradation dudit courant induit dans lesdites portions de parois de récipient, et laquelle méthode comporte en outre l'étape de

correction du premier signal reçu relativement aux effets desdits moyens de jointure en normalisant le premier signal reçu par rapport à ladite dégradation de référence sur les périodes intermédiaires dudit temps de dégradation, ladite dégradation de référence étant créée au moyen de l'objet servant d'antenne émettrice et de l'objet servant d'antenne de réception (27) placés à une certaine distance d'un moyen de jointure sur un récipient de telle sorte que la dégradation de référence ne soit pas affectée par lesdits moyens de jointure.

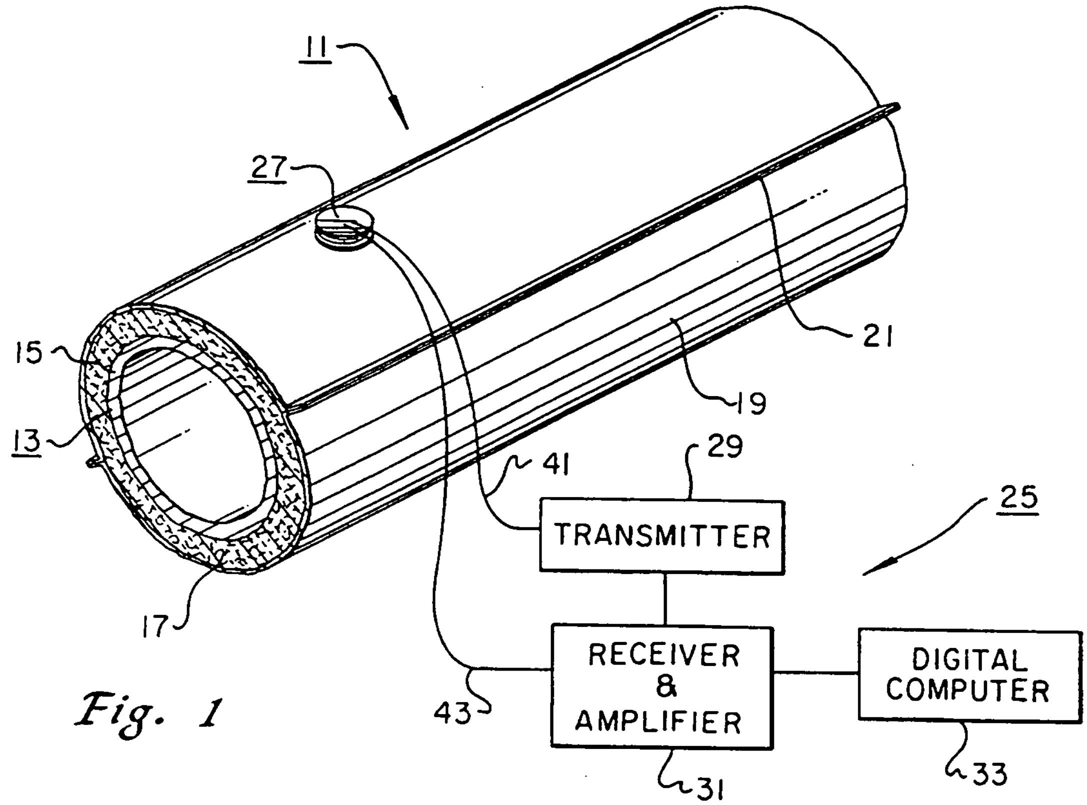

Fig. 1

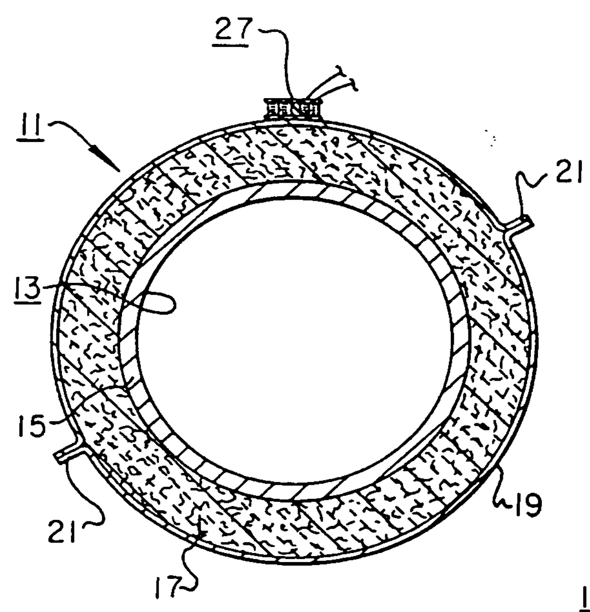

Fig. 2

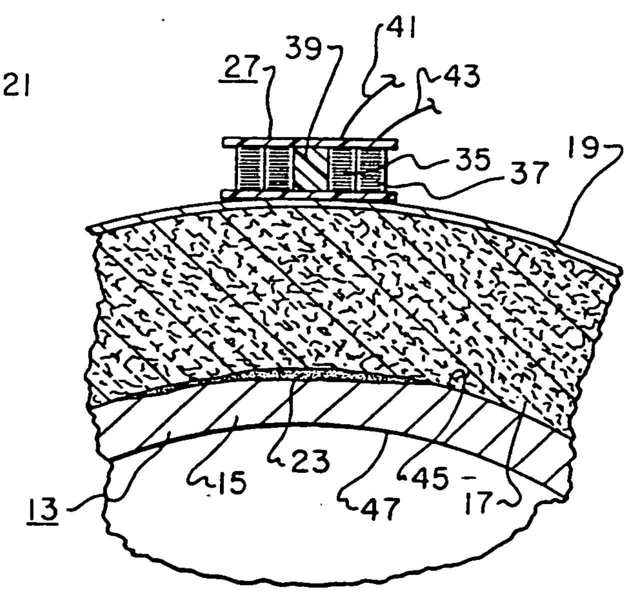

Fig. 3

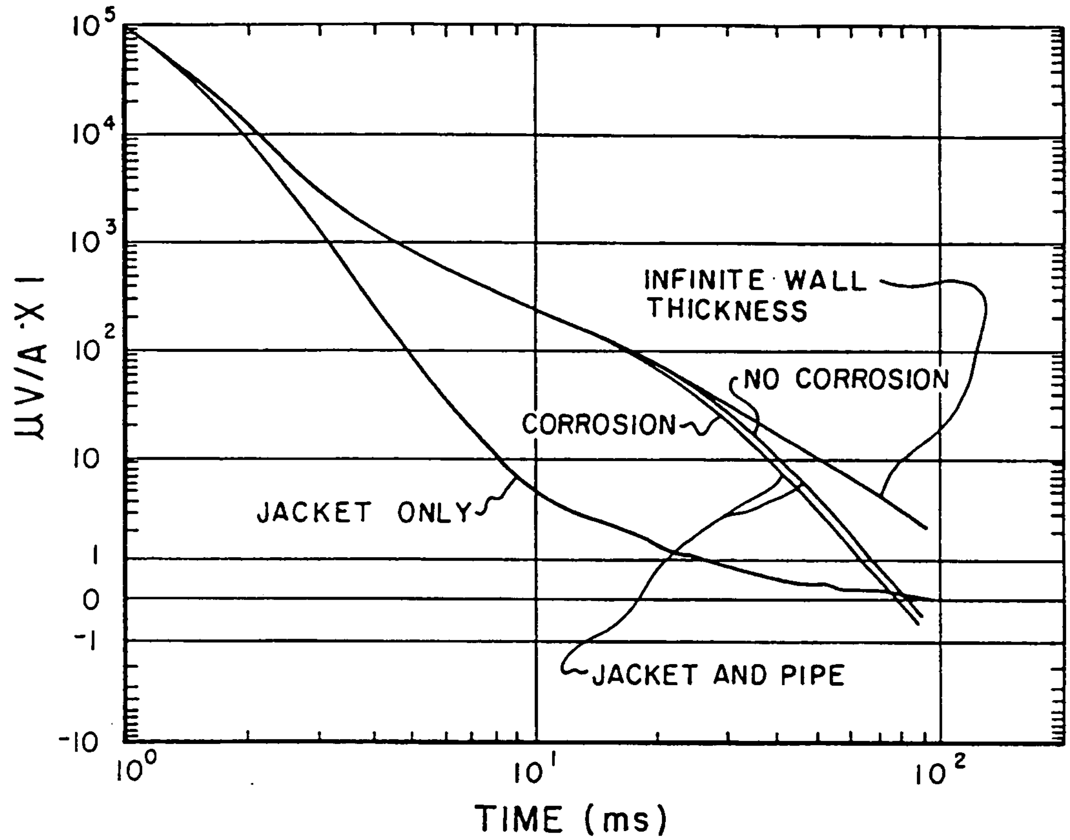
10^5
10^4
10^3
10^2
10
1
0
-1
-10
$\mu V/A \cdot X\,I$
INFINITE WALL THICKNESS
NO CORROSION
CORROSION
JACKET ONLY
JACKET AND PIPE
10^0
10^1
10^2
TIME (ms)

Fig. 4

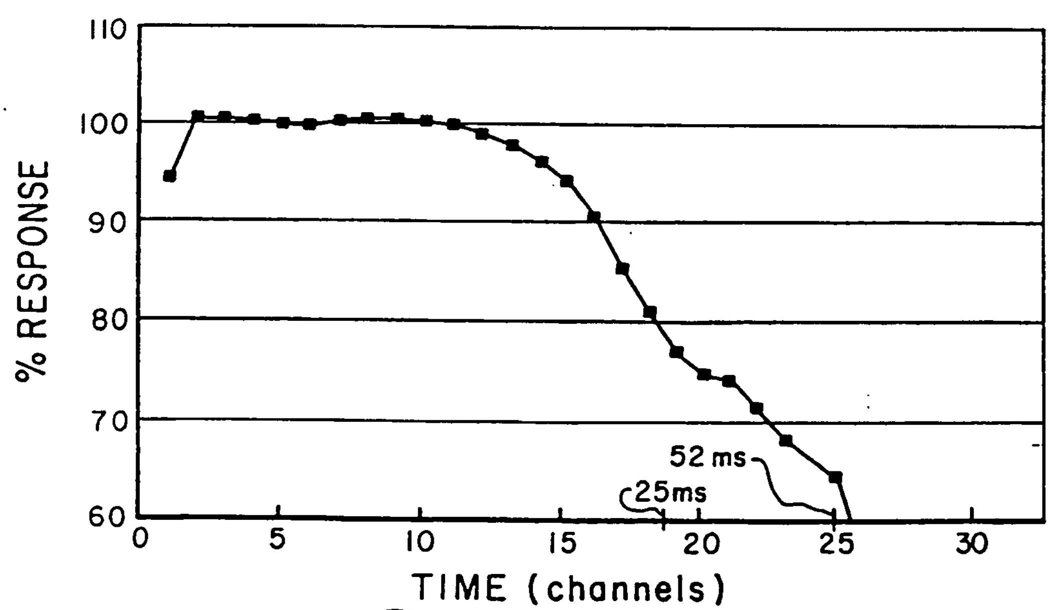
110
100
90
80
70
60
% RESPONSE
52 ms
25ms
0
5
10
15
20
25
30
TIME (channels)

Fig. 5

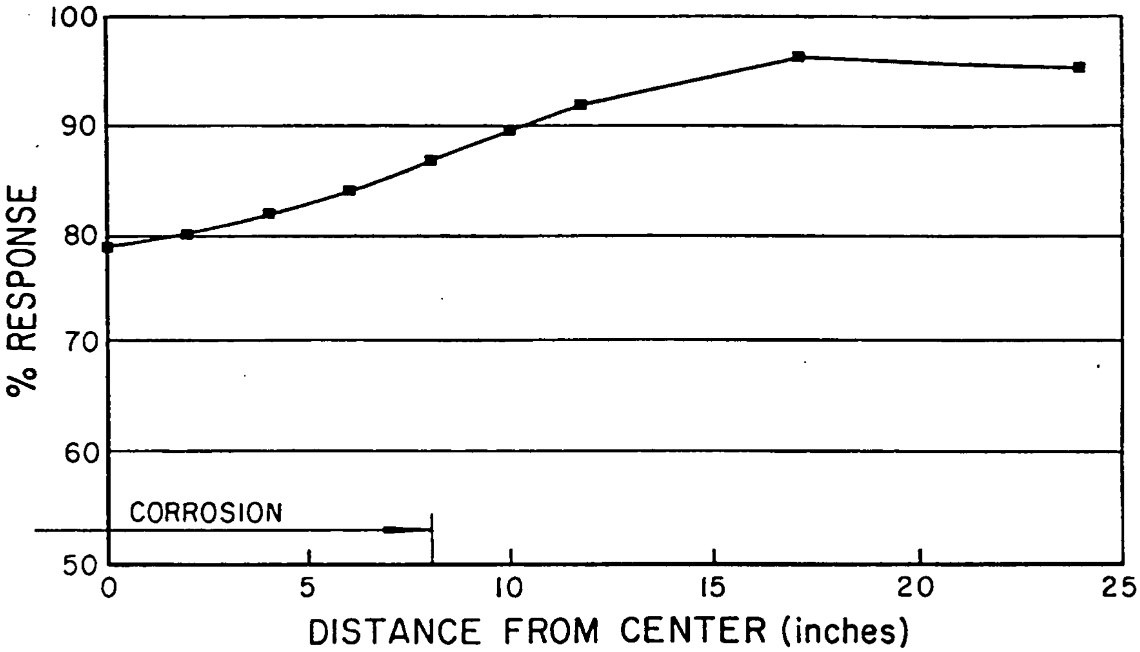
100
90
80
70
60
50
% RESPONSE
CORROSION
0
5
10
15
20
25
DISTANCE FROM CENTER (inches)

Fig. 6

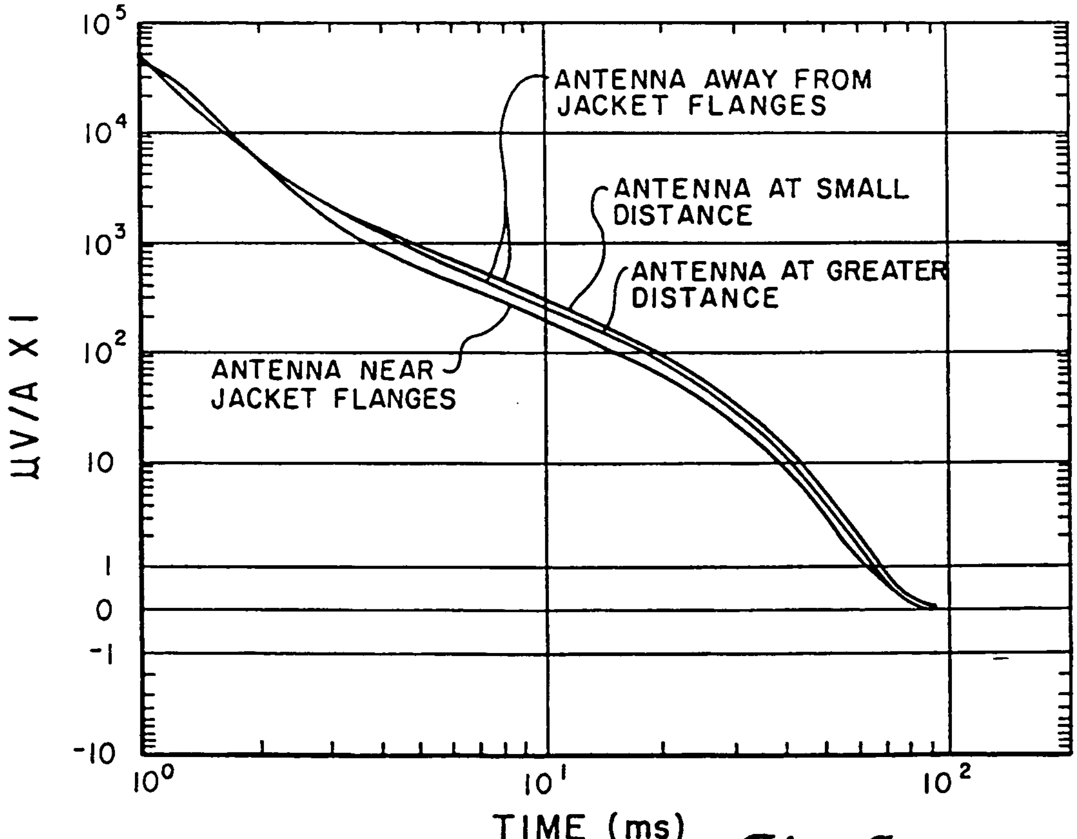
10^5
10^4
10^3
10^2
10
1
0
-1
-10
µV/A X I
ANTENNA AWAY FROM JACKET FLANGES
ANTENNA AT SMALL DISTANCE
ANTENNA AT GREATER DISTANCE
ANTENNA NEAR JACKET FLANGES
10^0
10^1
10^2
TIME (ms)

Fig. 7

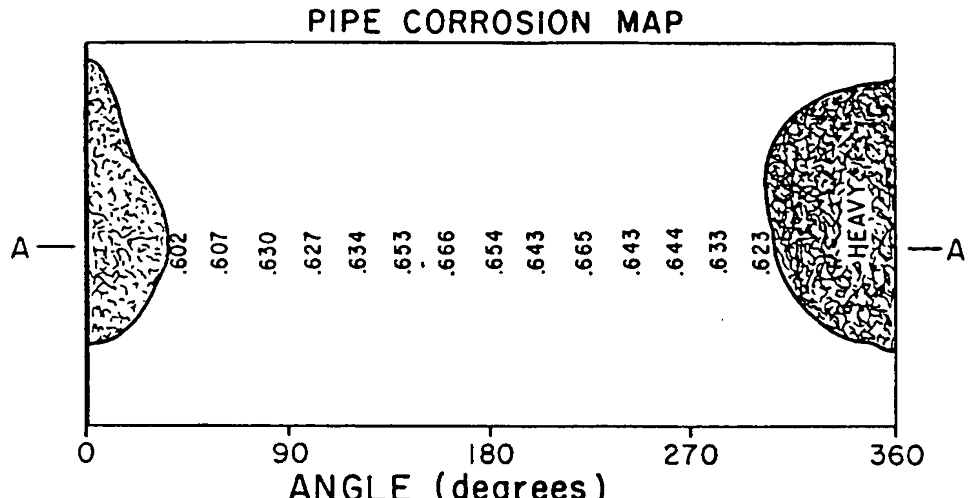
PIPE CORROSION MAP
A
.602
.607
.630
.627
.634
.653
.666
.654
.643
.665
.643
.644
.633
.623
HEAVY
A
0
90
180
270
360
ANGLE (degrees)

Fig. 8a

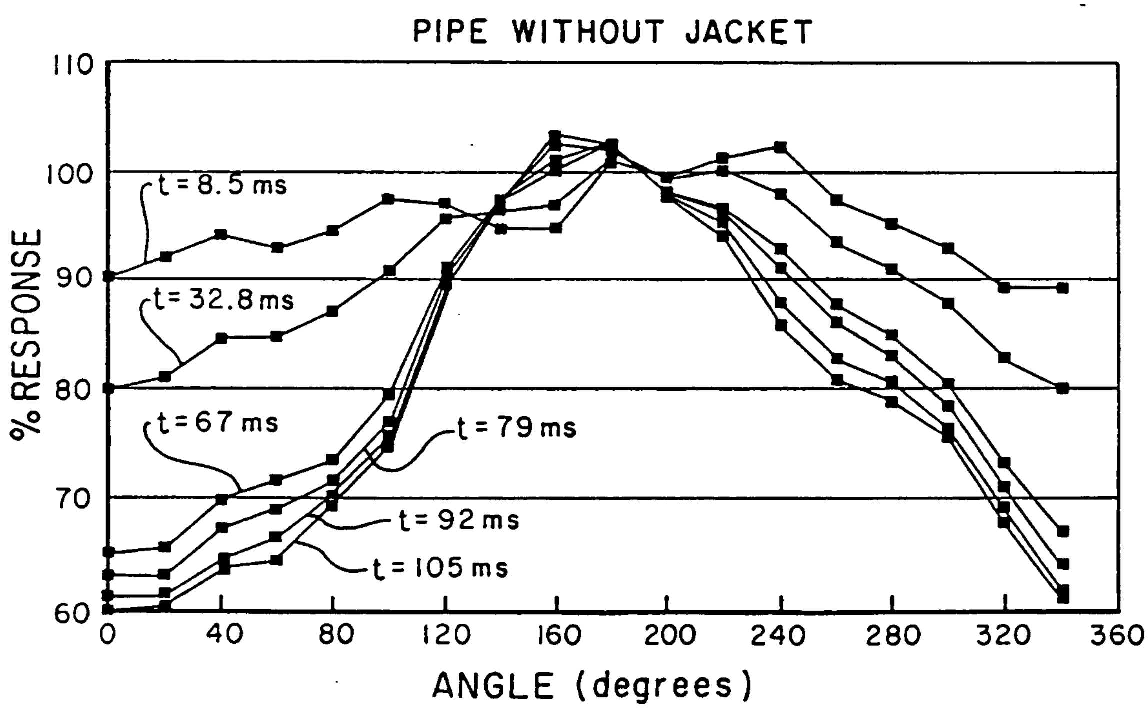
PIPE WITHOUT JACKET
% RESPONSE
110
100
90
80
70
60
t = 8.5 ms
t= 32.8 ms
t = 67 ms
t = 79 ms
t = 92 ms
t = 105 ms
0
40
80
120
160
200
240
280
320
360
ANGLE (degrees)

Fig. 8b

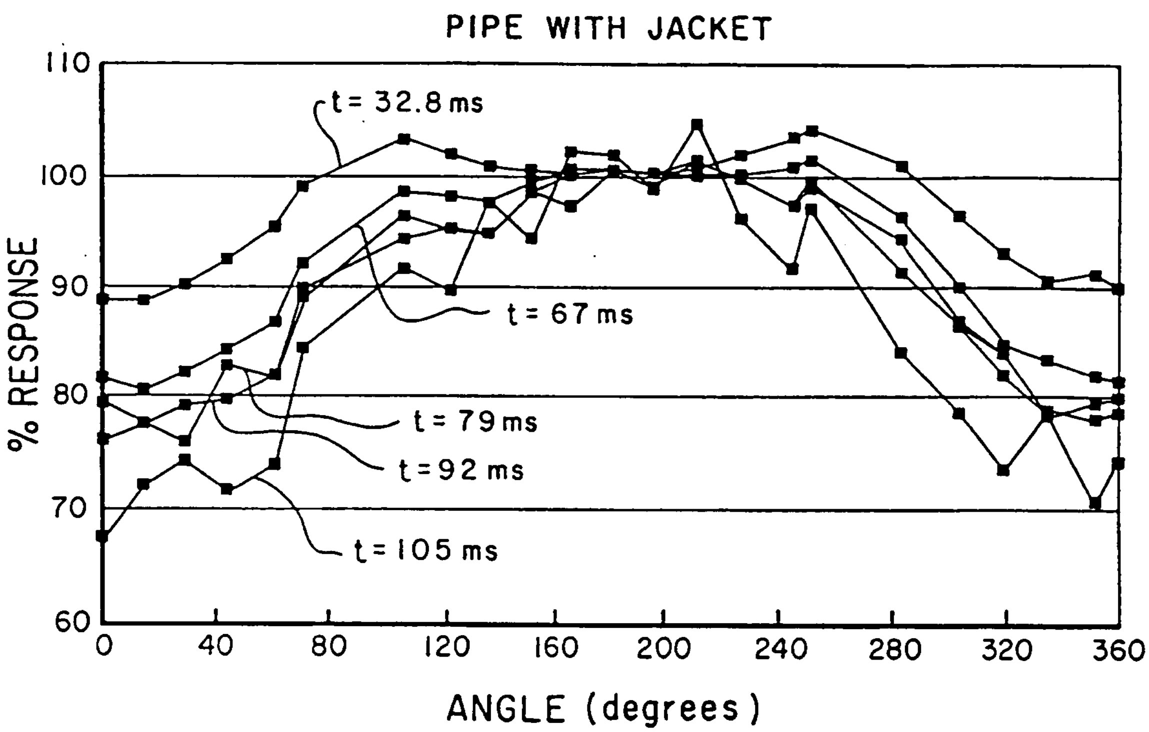
PIPE WITH JACKET
t = 32.8 ms
t = 67 ms
t = 79 ms
t = 92 ms
t = 105 ms
% RESPONSE
ANGLE (degrees)
110
100
90
80
70
60
0
40
80
120
160
200
240
280
320
360

Fig. 8c

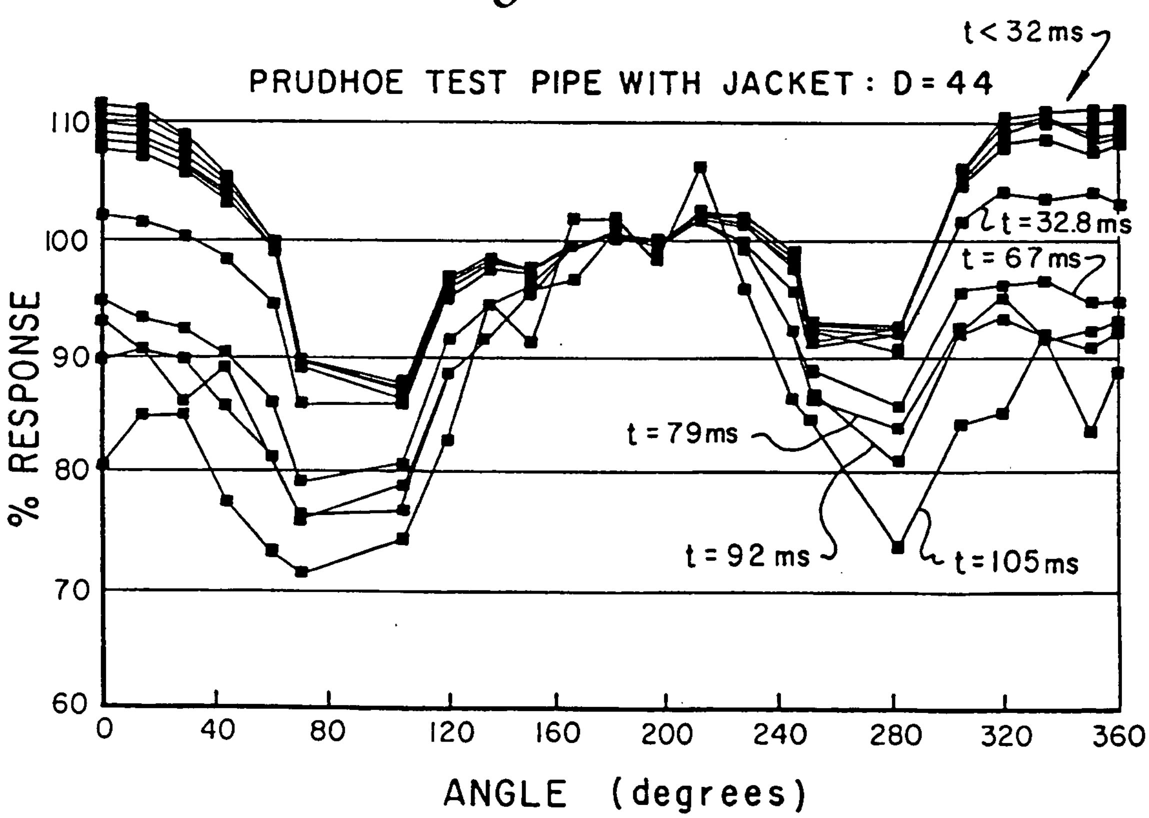
t < 32 ms
PRUDHOE TEST PIPE WITH JACKET : D = 44
t = 32.8 ms
t = 67 ms
t = 79ms
t = 92 ms
t = 105ms
% RESPONSE
ANGLE (degrees)
110
100
90
80
70
60
0
40
80
120
160
200
240
280
320
360

Fig. 8d